Extending a user interface prototyping tool with automatic MISRA C code generation

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Keywords

- User interface prototyping tool
  - malfunctions often arise from ill-designed interfaces
  - realistic simulations help understand and validate user interactions
- Formal specification
  - formal specifications reduce the risk of design errors
- **MISRA C code generation**
  - automatic code generation from validated models improves dependability

Model-driven development and formal models

MDD is essentially:

- Creating an executable model
- validating the model by simulation
- implementing the model by automatic code generation

The model is usually expressed in a block-based graphical language.

The language is formal in that it has a well defined semantics, but . . .

. . . **it has not been conceived** with formal verification in mind.

By **formal model** we mean a simulatable, executable and formally verifiable model.

Formal models enrich MDD by adding formal verification to simulation.

Background: The Prototype Verification System

Proving:

The PVS is an interactive theorem prover environment based on:

- A **typed higher-order logic** language
- a **sequent calculus** deduction system.

A PVS **theory** is a collection of definitions and statements, including axioms.

A PVS model is a collection of theories describing a system.

A system's requirement is expressed as a **theorem** to be proved wrt the theory.

Animating:

The PVSio extension is a **ground evaluator** that translates PVS function definitions into LISP code.

A PVS function definition may contain applications of **extra-logical** functions, providing, e.g., input and output.

A PVS model can then be animated, i.e., **simulated**.

PVSio-web and Emucharts

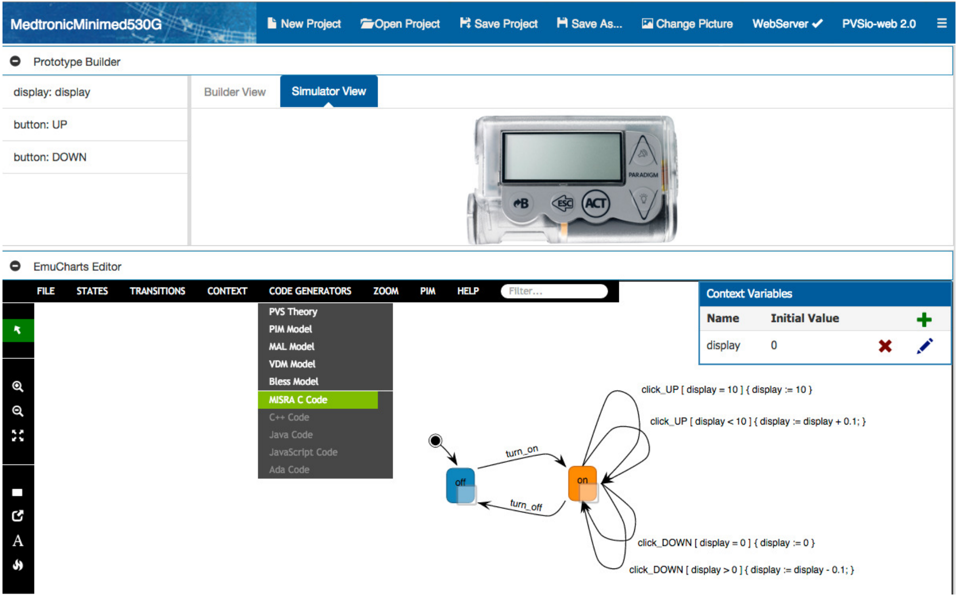
PVSio-web is a framework for prototyping and simulation of interactive device interfaces.

- Originally conceived for medical devices
- A formal model of the interface can be written in PVS, or
- entered in the graphical **Emucharts** language and translated to PVS
- PVS functions are associated with **active areas** of device pictures.

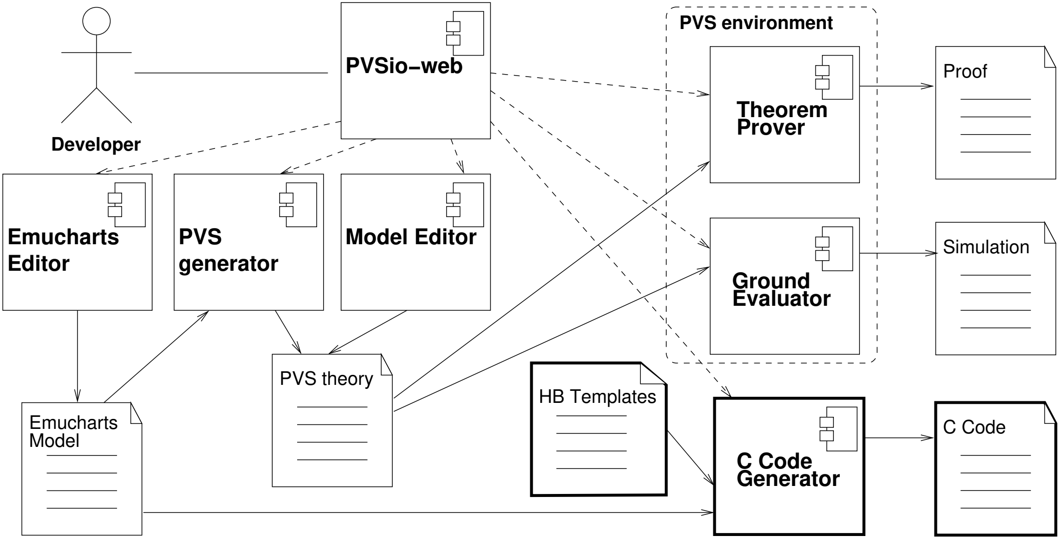
Users

- access the PVSio-web framework with any web browser, and
- interact with the simulated device clicking on buttons in the device picture.

The PVSio-web user interface



Code generation in the PVSio-web development process



Code generation

The C language was chosen as a target language due to its widespread use in embedded systems.

The MISRA (Motor Industry Software Reliability Association) guidelines were adopted to enhance dependability.

The C code generator produces the **source code** for a **module** implementing the interface subsystem of the device.

The generated module can be linked to software to **control** the actual device or **simulate** it.

From Emucharts to MISRA C

Emucharts is a formal **state machine** language with **guards**, **context variables**, and **actions** on context variables.

PVSio-web stores Emucharts diagrams in **Json** files

Handlebars templates extract information from Json files and insert them into C code text.

For each transition trigger (**input event**) τ, two functions are generated:

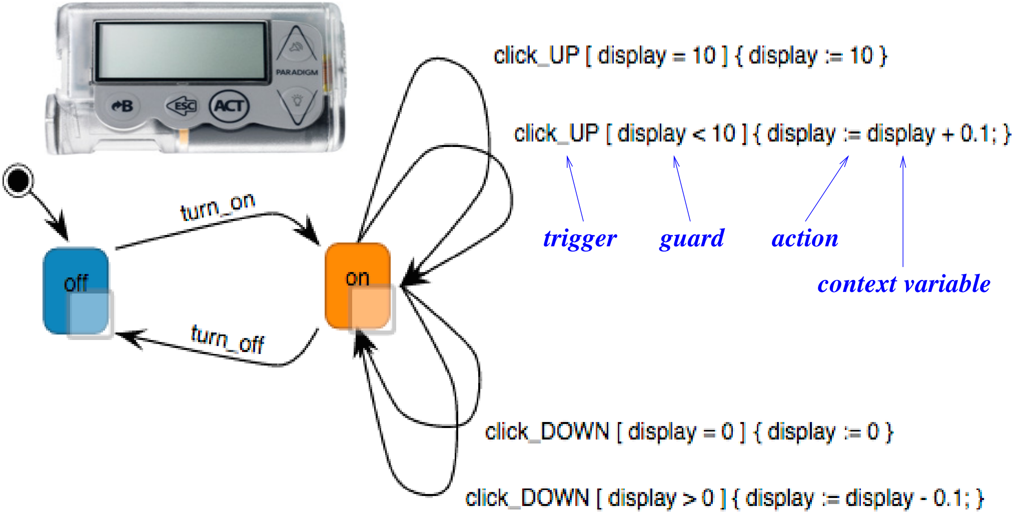
- a **permission** function checks if any transition from the current state is triggered by τ, and if so
- a **transition** function checks whether the guard (if any) is satisfied and executes the transition accordingly.

Translation mechanics

The C code generator is a JavaScript module that parses the JSON representation of a diagram and produces code (and documentation) from Handlebars templates:

```
{{#if states}}
/** * Enumeration of state labels. */
typedef enum {
    {{#each states~}}{{name}}{{#unless @last}},{{/unless}}
{{/each}}
} MachineState;{{/if}}
...
{{#if transitions}}/* definition of permission function */
{{#each transitions}}{{#if id}}UC_8 per\_{{id}}(const state *st)
{
    if(st->current_state == {{source.name}}){
        return true;
    }
    return false;
}{{/if}}{{/each}}{{/if}}
```

Example: Emucharts diagram for MiniMed 530G data entry



C code for MiniMed 530G data entry (1)

```
typedef enum { off, on } node_label;    %
typedef struct {                        % state representation
    D_64 display;                       %
    node_label curr_node;               %
    node_label prev_node; } state;      %

UC_8 per_click_UP(const state* st) {    % permission function
    if (st->current_state ==  on) {
        return true;
    }
    return false;
}
```

D_64 (double float, 64-bit) and **UC_8** (unsigned char, 8-bit) are MISRA C type aliases.

C code for MiniMed 530G data entry (2)

```
state click_UP(state* st) {                % transition function
    assert(st->current_state ==  on);
    assert(st->display < 10 || st->display == 10);
    if (st->display < 10 && st->current_state == on) {
        st->display = st->display + 0.1f;
        enter(on, st);
        assert(st->current_state == on);
        return *st;
    }
    if (st->display == 10 && st->current_state == on) {
        st->display = 10.0f;
        enter(on, st);
        assert(st->current_state == on);
        return *st;
    }
    return *st;
}
```

PVS theory for MiniMed 530G data entry (1)

```
  %-- machine states
  MachineState: TYPE = { off, on }

  %-- emuchart state
  State: TYPE = [#
    current_state: MachineState,
    previous_state: MachineState,
    display: real
  #]
...
  per_click_UP(st: State): bool =
    ((current_state(st) = on) AND (display(st) < 10))
    OR ((current_state(st) = on) AND (display(st) = 10))
```

PVS theory for MiniMed 530G data entry (2)

```
click_UP(st: (per_click_UP)): State =
  COND
   (current_state(st) = on) AND (display(st) < 10)
    -> LET new_st = leave_state(on)(st),
           new_st = new_st WITH [ display := display(st) + 0.1 ]
         IN enter_into(on)(new_st),
   (current_state(st) = on) AND (display(st) = 10)
    -> LET new_st = leave_state(on)(st),
           new_st = new_st WITH [ display := 10 ]
         IN enter_into(on)(new_st)
  ENDCOND
```

An application: the Alaris GP infusion pump

A volumetric infusion pump with a wide range of infusion rates (1 ml/h to 1200 ml/h).

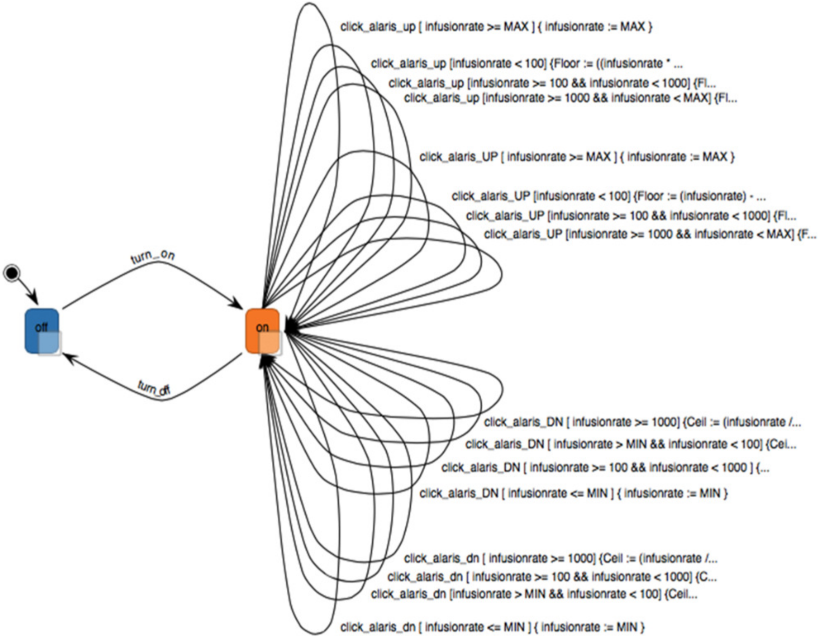
A floating point display with **three significant digits.**

Numerical input through **single-** and **double-chevron** buttons.

Numerical input for infusion rate

- If the displayed value *d* is < 100,
  - a single-chevron button adds ± 0.1
  - a double-chevron button changes the value to the next higher or lower decade (e.g., from 9.1 to 10.0)
- If $100 \leq d < 1000$,
  - a single-chevron button adds ± 1
  - a double-chevron button changes the value to the next higher or lower hundred plus the decade of *d* (e.g., from 314 to 410)
- If $d \geq 1000$,
  - a single-chevron button adds ± 10
  - a double-chevron button changes the value to the next higher or lower hundred (e.g., from 1010 to 1100)
- Buttons have no effect when the maximum or minimum allowed rate values are displayed.

Emucharts diagram for numerical data entry



A mobile application

The generated C code can run on a **mobile device.**

Interactive simulations on a mobile device are more realistic and can be used for **training** purposes.

The user interface code generated for the Alaris GP has been ported to the Android platform.

Conclusions

Code generation enables the PVSio-web framework to close the MDD cycle, from formal specification to industry-standard code:

- Developers (possibly unfamiliar with the PVS language) build a device interface model with the graphical, state-machine based Emucharts language.
- The model can be both verified by theorem proving and validated by simulation.
- The verified/validated model is implemented automatically by C code generation.

Thank you

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